

The Vacuum Spark Spectrum of Silicon

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ABSTRACT

Vacuum-spark spectrum of silicon, λ 6700– λ 2100.—Silicon electrodes less than a millimeter apart were mounted in a suitably designed brass box with a quartz window, the best obtainable vacuum was produced, and a highly condensed spark was obtained by the use of 70,000 volts. Lines of iron, aluminum, calcium, and oxygen and the strongest lines of hydrogen, nitrogen, copper, zinc, and titanium appeared as impurities. The wave-lengths of 227 lines attributed to silicon in the region λ 6700– λ 2100, together with the measurements of other observers, are given in Table I. An additional 75 lines, listed in Table II, are given as doubtful, since they were faint lines appearing on only one plate. In the intervals λ 6700– λ 5500 and λ 4070– λ 3400 the wave-lengths are believed to be accurate to within 0.2 Å and in the intervals λ 5500– λ 4070 and λ 3400– λ 2100 to within 0.1 Å.

I. INTRODUCTION

Silicon is one of the most widely distributed of all the chemical elements, but is difficult to isolate in a pure state. Moreover the slight conductivity of pure silicon renders its use with ordinary light sources very difficult. It is not surprising, then, that most of the earliest spectroscopic work on silicon was done with its compounds only. Kayser¹ has summarized all of the important work on silicon up to 1912. The first work Kayser mentions dates back as far as 1859, when Plücker investigated the light given off by an electrical discharge in various gases and vapors in a Geissler tube. Using silicon chloride, Plücker found four lines which he attributed to silicon. Of those who followed, Rowland was the first to point out the presence of silicon in the sun, and Lockyer identified silicon lines in the spectra of many of the stars. Up to 1912, however, none of the work on silicon seems to have been particularly satisfactory.

The most recent work on the spectrum of silicon was done by Sir William Crookes² in 1914. He succeeded in obtaining some rather pure samples of silicon, and using a condensed spark between

¹ *Handbuch der Spectroscopie*, 6, 478–494.

² *Proceedings Royal Society*, Series A, 90, 512–520, 1914.

electrodes of this silicon, photographed the spectrum with a prism spectrograph. The rapid oxidation of the silicon made it very difficult to maintain the spark and necessitated long exposures. His work covered the region λ 6500 to λ 2100 and he published the wave-lengths of 43 lines, including most of the lines previously recorded. This investigation was the most thorough work that had been done on silicon up to that time. Since the work of Crookes, Fowler¹ has mentioned observing four lines in the visible region of the spectrum, not previously observed; and McLennan² has extended the investigation into the extreme ultra-violet, cataloguing some seventeen additional lines.

A comparison of the results of all the work that has been done on silicon brings out the fact that no two observers have the same list of lines, and also shows that even in the lines that have been recorded by several observers, the disagreement in wave-length seems almost unaccountably large. This disagreement may be partly accounted for, however, by the fact that many of the silicon lines are especially broad and hazy when produced at atmospheric pressure.

The importance of having accurate and complete results on the spectrum of silicon can well be realized when one considers the wide terrestrial distribution of this element, as well as the fact that its presence in many of the stars has been definitely established. Complete and accurate data on the spectrum of silicon are also desirable to throw new light on its spectral series, the details of which have not yet been completely worked out. With the discovery of the vacuum-spark, a new source of light became available that seemed to have particular advantages in this problem. The use of the vacuum-spark in extending the spectrum into the extreme ultra-violet,³ had given results which led to the expectation that it might give new information in the rest of the spectrum. With this in mind, it was decided to photograph the vacuum-spark of silicon in the region covered by Crookes, hoping that the results might give more accurate information concerning the wave-lengths of some

¹ *Monthly Notices*, 74, 196-197, 1916.

² *Philosophical Magazine*, 30, 482-484, 1915.

³ *Astrophysical Journal*, 52, 286-300, 1920.

of the lines and even add to the already known list. In adapting the vacuum-spark to silicon, it was found necessary to use high voltage and extremely good vacua; but once obtained, the spark was brilliant, of a reddish yellow color, and resembled the vacuum-spark of carbon.

II. DESCRIPTION OF APPARATUS AND MANIPULATIONS

A 100,000-volt closed-core transformer gave the necessary voltage. Energy was supplied to the primary from a 110-volt power circuit, and controlled by a heavy rheostat in series with the primary. To prevent overheating the transformer and the silicon electrodes, a commutator switch was placed in the primary and adjusted so that the current was automatically turned on forty times a minute for about one half a second at a time. One terminal of the high voltage transformer was connected directly to one of the electrodes; the other terminal was grounded. By grounding the second electrode, the circuit was completed with only one line charged to a dangerous voltage.

In order to have a large amount of energy available when the spark passed, a capacity consisting of five glass condensers, immersed in oil and connected in series, was placed in parallel with the gap. This arrangement gave a capacity of the order of magnitude of one one-hundredth of a microfarad, while the voltage over any one condenser was not sufficient to puncture the glass dielectric.

The vacuum was obtained with two mercury diffusion pumps designed to work in series, and a small oil pump as a pre-pump. The vapor pressure of the mercury at room temperature was too great to permit a sufficiently high vacuum to be obtained. To reduce this vapor pressure, a glass trap was sealed in between the spark box and the pumps. When this trap was immersed in liquid air, the pressure due to any vapors present was sufficiently reduced so that vacua could be obtained that would remain non-conducting for sparking voltages of roughly 70,000 volts with a spark-gap length of less than one millimeter. It was found that, with the pumps working well, such a vacuum could be obtained in about five minutes. The pressure was then of the order of magnitude of one ten-thousandth of a millimeter of mercury or less.

Since the spark box was heated somewhat by the spark radiation, and the electrodes themselves heated to a white heat the instant the spark passed, frequent adjustments of the spark were necessary. To accomplish these adjustments without opening the box, the electrodes were mounted eccentrically in insulating plugs ground into brass tubes soldered to opposite ends of the box. The electrodes could then be rotated inside the box without affecting the vacuum. One electrode was mounted on a nut which ran on a shaft that could be rotated from the outside in such a way as to move the electrode in or out as desired, and thus regulate the distance between the electrodes. The box was made with one removable side. Leakage was prevented by the use of a rubber gasket and a rubber stopcock grease prepared for the purpose. This removable side made it possible to renew the electrodes and clean the windows through which the spark was photographed.

The electrodes themselves consisted of small pieces of elementary silicon mounted in brass clamps. Pure silicon is very hard and brittle, and the electrodes could be shaped to rough points only by chipping. The silicon was very kindly furnished by the Carborundum Company of Niagara Falls, who also furnished that used by Crookes and McLennan.

With the electrodes adjusted so that they were all but touching, a spark could be obtained with a comparatively poor vacuum. This spark was very feeble; for most of the energy available was dissipated by conduction through the gas remaining in the box. With the best vacuum that could be obtained, the distance between the electrodes could be made somewhat larger, but never more than about a millimeter for silicon electrodes. The spark under these conditions was extremely brilliant. The electrodes became white-hot almost instantly, and some of the silicon was vaporized, eventually fogging the windows through which the spark was photographed. If the power was kept on for more than a second at a time, occluded gases from the electrodes and their insulators were given off in sufficient quantity to stop the spark. In spite of the very refractory nature of silicon, the electrodes were worn away rapidly, and frequent adjustments and renewals were necessary.

To photograph the spark, two spectrographs were used, both of which were designed and built during the course of this research.

The region $\lambda 6700$ to $\lambda 4070$ was photographed by a glass spectrograph of the Littrow type. A 3-inch telescope objective lens with a focal length of roughly 24 inches was used. It was a cemented doublet and gave a reasonably flat field. The refracting angle of the prism was 60° , and its face about an inch and a half across. The entire region $\lambda 6700$ to $\lambda 4070$ was photographed on a 5-inch plate. Exposures with this instrument extended sometimes over 15-hour periods, making it necessary to house the entire spectrograph to prevent shifts due to changes in temperature.

The region $\lambda 4100$ to $\lambda 2100$ was photographed by a quartz spectrograph of a type first described by Fabry and Buisson.¹ In this instrument, the slit was mounted directly over the middle of the prism. A platinized concave mirror of 32-inch focal length served to collimate the light from the slit. The prism consisted of a cemented doublet of right and left quartz—the whole having an oblong face 1.75 inches high and a refracting angle of 60° . The light, after passing through the prism, was focused on the plate by a quartz lens whose focal length was 35.7 inches for the "D" lines. The use of only one quartz lens has the advantage of making the focal plane of the instrument more nearly perpendicular to the axis of the lens, since the collimating mirror insures parallelism of the beams of every wave-length incident on the prism. The inclination of the plate is due wholly to the variation with wave-length of the focal length of the camera lens. Thus, in this instrument, the photographic plate is at an angle of 45° to the axis rather than at 30° , as in an instrument of similar power but using a single quartz collimating lens. A shorter plate is thus used and yet the increased sharpness of the lines due to the lesser inclination more than offsets the shortness of the spectrum. With the quartz instrument, the whole region from $\lambda 6000$ to $\lambda 2000$ was photographed on a 10-inch plate. Only the region $\lambda 4100$ to $\lambda 2000$ was sufficiently dispersed, however, for satisfactory measurements. The copper line at $\lambda 1944$ has been photographed with this instrument, but no lines below $\lambda 2100$ were observed in the silicon spectrum.

For the region $\lambda 6700$ to $\lambda 4070$, radiation from the spark was focused on the slit with a lens. In order to be sure that the radia-

¹ *Journal de Physique*, 9, 929, 1910.

tion from the iron comparison arc would enter the slit at exactly the same angle as that from the vacuum-spark, the arc was placed beyond the spark box and on the extension of the line joining the slit and the silicon spark gap. A short focus lens formed an image of the arc between the spark electrodes. This insured identity of source for the known and unknown spectrum. The iron arc was used as a standard, as very complete data on the wave-lengths of these spectral lines are now available. These data were taken from results obtained at Mount Wilson¹ and at Bonn,² Germany. For the quartz instrument, no external source comparison was necessary as it was found that the iron occurred as an impurity in the silicon. An iron comparison spectrum was photographed on the plate, however, to help in identifying the spark lines.

For the visible region, a special type of panchromatic plate, manufactured by Ilford, London, England, was found most satisfactory. Ordinary Seed plates were used in the ultra-violet.

In order to guard against any possible error due to changes in the optical set-up during any one exposure, the iron comparison arc radiation was admitted to the spectrograph at the beginning, at the end, and eight to ten times at intervals during the exposure. This precaution was not necessary, of course, with the ultra-violet plates, as sufficient standard lines existed as impurities in the silicon spark itself.

III. MEASUREMENTS AND RESULTS

The plates were measured on a large engine kindly made available by the Detroit Observatory of the University of Michigan. The reductions were made by using the Hartmann interpolation formula, and the final wave-lengths expressed in International Angstroms. The results show that the probable error for the region λ 6700 to λ 5500 is about 0.2 angstroms; from λ 5500 to λ 4070 less than 0.1 angstroms; from λ 4070 to λ 3400 about 0.2 angstroms; and from λ 3400 to λ 2100 less than 0.1 angstroms. It is unfortunate that only two plates were obtained with the quartz instrument and the

¹ *Astrophysical Journal*, **53**, 260, 1921.

² *Zeitschrift für Wissenschaftliche Photographie*, **12**, 207-235, 1913; and **19**, 149-157, 1919.

possible error is therefore larger in the region λ 4070 to λ 2100. The results from λ 6700 to λ 4070 are the mean observations from eight plates and are correspondingly more reliable.

In general, conclusions as to the accuracy of the present work were drawn from the variation in wave-lengths of the lines between individual plates, and from the accuracy with which determinations were made on impurity lines of known wave-length. It is of interest to note, in considering the accuracy, that interferometric measurements of wave-length have been made by Fabry and Buisson on three ultra-violet silicon lines.¹ The following table shows the comparison of their results with the present work.

Fabry and Buisson	Vacuum-spark	Intensity	Difference
2528.516	2528.50	5	0.016
2506.904	2506.90	4	0.004
2435.159	2435.17	5	0.011

Such an agreement as this leads to the belief that the error estimates given above are, at least for the strong lines, conservative.

Altogether over 700 lines have been measured in the spark spectrum of silicon, and of this number some 400 have been identified as due to the elements which occurred as impurities in the source. This leaves a list of more than 300 lines that have been ascribed to silicon. Of this number, 75 are classified as "doubtful" lines (see Table II). These lines are mostly very faint and have been observed on one plate only. Although the possible error in their wave-lengths may be somewhat larger than for the rest, and in many cases their actual existence may be in doubt, still they have been listed, and evidence is in favor of retaining them. The photographs were taken under varying conditions as to exposure time, voltage used on the spark, length of spark gap, plate developing, and kind of plate; and many other lines, equally faint, have been measured and found to be due to impurities. The main list (Table I) contains only those lines concerning which there can be little doubt. All possible impurities have been very carefully checked, and where there was any reasonable doubt, the line in question has been eliminated. There still remain in this list some 224 lines where previously less than 80 had been observed.

¹ *Astrophysical Journal*, 27, 169, 1908.

The wave-lengths are given in International Angstrom Units, whereas those by other observers are in the Rowland System. In general, the wave-lengths agree fairly well. In some cases, however, there exist variations of more than an angstrom. Such disagreement is hard to explain, and no such disagreement has been found in the results from the various plates measured during the course of the present work. The lines in most cases are sharp. General fogging of the plate due to band spectra of nitrogen or carbon, such as occurs in the ordinary spark in air or in the carbon arc, is entirely absent. Faint lines that under ordinary conditions would be obliterated, are, under the conditions of the vacuum-spark, measurable.

Of the impurities that appeared, only a very few can be attributed to remnants of gases in the vacuum chamber. The hydrogen line, $H\alpha$, showed faintly on only a few plates; $H\beta$, on two plates; $H\gamma$, and the remaining hydrogen lines, not at all. A few of the strongest mercury lines were recorded, and five of the strongest nitrogen lines. The strongest copper and zinc lines appear, coming probably from the brass clamps in which the silicon was mounted—there was usually a little sparking from the clamps. The lines which appeared due to impurities in the silicon itself are more numerous. In the visible, a few of the strongest iron lines appeared, but in the ultra-violet practically the entire spark spectrum of iron was observed. The appearance of the iron spectrum made unnecessary the use of a separate iron arc comparison, and eliminated any possibility of lack of identity in position of the silicon and the comparison source. Titanium, which Crookes mentioned as the principal impurity, appeared not at all in the visible, while only a few of the very strongest lines showed faintly in the ultra-violet. The entire spectrum of aluminum appeared in the visible, together with all but a few of the fainter arc lines in the ultra-violet. Of the two new aluminum lines observed by Shallenberger,¹ the one at $\lambda 4150$ came out strongly on all the plates, but the other one, at $\lambda 2907$, showed not at all. All of the strong oxygen lines appeared faintly, denoting probably a trace of oxide in the sample. One boron line showed, and a few carbon lines. The sodium D

¹ *Physical Review*, 19, 398-399, 1922.

lines appeared extremely faint. H and K of calcium appeared strong, together with the calcium line at $\lambda 4227$. Most of the other strong calcium lines appeared on some of the plates. The resonance lines of magnesium, barium, and strontium, described by De Gramont¹ as "raies ultimes," were also photographed. The character of the impurity lines showed that while arc lines certainly appear in the vacuum-spark, the spectrum which it gives tends to emphasize the spark lines.

There is, of course, the possibility that some of the new lines found are due to impurities and not to silicon. To guard against this possibility, the vacuum-spark spectra of aluminum and of carbon were photographed and checked against the silicon plates. Only the aluminum line, $\lambda 4150$, however, was thus eliminated. The vacuum-spark spectra of iron, calcium, magnesium, and titanium were photographed through most of this region by Miss Carter,² who did not report any new lines. As the principal impurities occurring in the source used in this work are thus covered, the possibility that any of the new lines are due to impurities seems slight.

In comparing the results obtained, with those of previous observers, the number of new lines found is surprising. With but one or two exceptions, all the lines that have ever been found, either in the arc or spark of silicon, have been photographed. A few of the lines ascribed by some to silicon have been assigned to impurities. Special note is made of these lines in Table I. The intensities are estimated arbitrarily, but give some insight into the nature of the lines, and agree in the main with others. Strangely enough, though, the most intense line in the ultra-violet, $\lambda 2541.91$, has been missed by some observers, and no one before found it to be the strongest.

Time has not permitted a study of the lines for possible series, but the spectrum certainly contains many doublets and some triplets of constant frequency difference. The most conspicuous is the set of doublets having a frequency difference of 60 waves per centimeter. Sixteen of these doublets have been observed. Among the triplets, the difference $-74-34-$ occurs five times with

¹ *Comptes Rendus*, 171, 1105-1109, 1920.

² *Astrophysical Journal*, 55, 162, 1922.

TABLE I
VACUUM-SPARK SPECTRUM OF SILICON

Wave-Length in Å. Units	Intensity	Rowland	Exner and Haschek	De Gramont and C. de Watteville	Eder and Valenta	Crookes
2122.33.....	0	.....	.....	.....	.....	.....
2123.77.....	I	.....	.....	2123.0	2124.17	2124.163
2135.90.....	2	.....	.....	.....	.....	.....
2148.81.....	I	.....	.....	.....	.....	.....
2179.37.....	2	.....	.....	.....	.....	.....
2189.62.....	2	.....	.....	.....	.....	.....
2192.22.....	3	.....	.....	.....	.....	.....
2208.01.....	2	2208.01	2208.06	2208.8	2208.1	2208.048
2210.92.....	3	2210.94	2210.97	2211.0	2210.9	2210.987
2211.76.....	2	2211.76	2211.84	2212.0	2211.8	2211.839
2216.71.....	3	2216.76	2216.75	2217.2	2216.76	2216.882
2218.11.....	3	2218.15	2218.13	2218.7	2218.15	2218.227
.....	.....	.....	2218.97	2219.5	2219.5	.....
2228.86.....	2	.....	.....	.....	.....	.....
2287.06.....	3	.....	.....	.....	.....	.....
2299.86.....	2	.....	.....	.....	.....	.....
(1).....	I	.....	2303.15	2303.8	2303.3	.....
2308.21.....	I	.....	.....	.....	.....	.....
2325.35.....	2	.....	.....	.....	.....	.....
2334.48.....	I	.....	.....	.....	.....	.....
2338.97.....	2	.....	.....	.....	.....	.....
2346.80.....	2	.....	.....	.....	.....	.....
2349.54.....	I	.....	.....	.....	.....	.....
2350.26.....	0	.....	.....	.....	.....	.....
2353.19.....	I	.....	.....	.....	.....	.....
2356.35.....	3	.....	.....	.....	2356.9	.....
2357.20.....	2	.....	.....	.....	.....	.....
2358.02.....	2	.....	.....	.....	.....	.....
2363.82.....	2	.....	.....	.....	.....	.....
2371.02.....	0	.....	.....	.....	.....	.....
2416.54.....	I	.....	.....	.....	.....	.....
2419.80.....	I	.....	.....	.....	.....	.....
2432.23.....	2	.....	.....	.....	.....	.....
2435.17.....	5	2435.25	2435.27	2435.6	2435.25	2435.212
(2).....	2	2438.86	2438.87	2439.4	2438.86	2438.911
2443.47.....	I	2443.46	2443.47	2443.5	2443.46	2443.484
(2).....	I	.....	2443.91	.....	.....	.....
(2).....	I	.....	2446.63	.....	2446.0	.....
2449.70.....	2	.....	.....	.....	.....	.....
2452.12.....	I	2452.22	2452.23	2452.5	2452.22	2452.219
2480.04.....	I	.....	2478.41	.....	2479.8	.....
2481.10.....	0	.....	.....	.....	.....	.....
2483.29.....	I	.....	.....	.....	.....	.....
2486.28.....	2	.....	.....	.....	.....	.....
2495.79.....	I	.....	.....	.....	.....	.....
2500.90.....	I	.....	.....	.....	.....	.....
2503.64.....	I	.....	.....	.....	.....	.....
2506.90.....	4	2506.99	2507.01	2506.8	2506.99	2507.055
2514.34.....	4	2514.42	2514.41	2514.3	2514.42	2514.406
2516.08.....	5	2516.21	2516.26	2516.0	2516.21	2516.131
2517.48.....	3	.....	.....	.....	.....	.....

TABLE I—Continued

Wave-Length in I.A. Units	Intensity	Rowland	Exner and Haschek	De Gramont and C. de Watteville	Eder and Valenta	Crookes
2519.22.....	3	2519.30	2519.30	2519.2	2519.30	2519.276
2524.11.....	4	2524.21	2524.21	2524.3	2524.21	2524.110
2528.50.....	5	2528.60	2528.60	2529.0	2528.60	2528.585
2532.41.....	I		2532.45	2533.0	2533.2	
(2).....	I			2535.0	2534.7	
2541.91.....	IO		2541.90		2541.89	2541.970
2559.20.....	4		2568.8	2569.0	2568.8	
2570.78.....	I					
2580.35.....	I					
2593.71.....	I					
(2).....	4	2631.39	2631.38		2631.39	2631.370
2637.92.....	I					
2640.89.....	2					
2645.59.....	I					
2649.47.....	O					
2650.73.....	2					
2658.29.....	O				2659.0	
2672.43.....	O				2673.3	
2675.25.....	2					
.....					2677.4	
2682.42.....	2					
2687.75.....	2				2689.8	
(*).....						
2695.28.....	2					
2697.20.....	I					
2701.53.....	I					
2716.25.....	I					
2813.61.....	I					
2831.40.....	2					
2858.14.....	I					
2866.28.....	I					
2869.73.....	I					
2873.10.....	I					
2881.70.....	7	2881.70	2881.73	2881.7	2881.70	2881.690
2899.52.....	2					
2904.01.....	2					
2905.59.....	2					
2924.04.....	2					
2976.42.....	I					
2987.99.....	2	2987.77	2987.77	2987.8	2987.77	2987.750
3002.37.....	I					
3012.55.....	I					
3034.37.....	O					
3043.70.....	2					
3086.44.....	5		3086.6	3087.2		3086.479
3093.28.....	4		3093.6	3094.5		3093.694
3096.92.....	3					
3103.80.....	I					
3106.14.....	I					
3130.48.....	3					
3147.01.....	I					
3149.67.....	4					

TABLE I—*Continued*

Wave-Length in I.A. Units	Intensity	Rowland	Exner and Haschek	De Gramont and C. de Watteville	Eder and Valenta	Crookes
3165.78.....	4	.....	.....	.....	.....	.....
3185.28.....	3	.....	.....	.....	.....	.....
3188.85.....	I	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	3191.1	.....
3192.69.....	I	.....	.....	.....	.....	.....
3196.12.....	2	.....	.....	.....	.....	.....
3199.42.....	2	.....	.....	.....	.....	.....
3203.87.....	2	.....	.....	.....	.....	.....
3210.27.....	3	.....	.....	.....	.....	.....
3230.43.....	2	.....	.....	.....	.....	.....
3234.05.....	3	.....	.....	.....	.....	.....
3241.80.....	4	.....	.....	.....	.....	.....
(1)	2	.....	.....	.....	.....	.....
3258.45.....	2	.....	.....	.....	.....	3247.684
3270.33.....	I	.....	.....	.....	.....	.....
3313.85.....	O	.....	.....	.....	.....	.....
3333.48.....	I	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	3438.444
3404.14.....	2	.....	.....	.....	.....	.....
3470.68.....	I	.....	.....	.....	.....	.....
3481.55.....	2	.....	.....	.....	.....	.....
3486.79.....	4	.....	.....	.....	.....	.....
3532.02.....	O	.....	.....	.....	.....	.....
3537.70.....	O	.....	.....	.....	.....	.....
3548.24.....	I	.....	.....	.....	.....	.....
3563.61.....	I	.....	.....	.....	.....	.....
3570.05.....	I	.....	.....	.....	.....	.....
3576.15.....	2	.....	.....	.....	.....	.....
3590.77.....	3	.....	3591.0	.....	.....	.....
3702.01.....	2	.....	.....	.....	.....	.....
3713.23.....	2	.....	.....	.....	.....	.....
3762.42.....	2	.....	.....	.....	.....	.....
3774.74.....	2	.....	.....	.....	.....	.....
3791.13.....	3	.....	3791.8	3791.5	3791.1	.....
3796.18.....	4	.....	3796.5	3796.0	3795.9	3796.364
3806.60.....	6	.....	3806.90	3807.0	.....	3806.802
(2)	I	.....	.....	.....	3826.7	.....
(2)	I	.....	.....	.....	3834.4	.....
3853.01.....	2	.....	3854.02	.....	3854.00	3853.812
3856.09.....	4	.....	3856.19	3856.0	3856.20	3856.193
3862.51.....	4	.....	3862.80	3862.5	3862.75	3862.743
3870.64.....	I	.....	.....	.....	.....	.....
3891.55.....	2	.....	.....	.....	.....	.....
3905.37.....	3	3905.66	3905.71	3905.5	.....	3905.726
3924.44.....	3	.....	.....	.....	.....	.....
3991.62.....	2	.....	.....	.....	.....	.....

(1) This line apparently due to copper.

(2) Lines in these positions attributed to iron.

**) A line here too faint to measure accurately.

TABLE I—Continued

Wave-Length in I.Å. Units	Intensity	Rowland	Exner and Haschek	De Gramont	Lunt	Crookes
4016.28.....	I					
.....			4021.0			
.....			4030.1			
4058.49.....	I					
4088.88.....	6				4089.0	4089.016
4102.62.....	0	4103.09	4103.2			
.....			4103.7			
4116.15.....	6				4116.35	
4128.11.....	8		4128.1	4128.2	4128.20	4128.189
4130.96.....	10		4131.0	4131.3	4131.08	4131.192
4183.67.....	0					
4190.92.....	2		4191.1		4191.00	
4198.25.....	2				4198.43	
4212.66.....	I					
4236.45.....	I					
4277.95.....	I					
4314.32.....	I					
4328.40.....	I					
4338.57.....	2					
4372.33.....	I					
4377.80.....	I					
4494.02.....	I					
4552.50.....	20		4552.75	4552.5	4552.82	4552.841
4567.66.....	16		4567.95	4567.0	4567.82	4568.123
4574.66.....	12		4574.90	4574.5	4774.86	4574.823
4619.60.....	I					
4631.22.....	2					
4632.94.....	I					
4638.36.....	I					
4654.08.....	4					
4665.76.....	I					
4673.45.....	0					
4683.10.....	2					
4709.20.....	1					
4716.71.....	4					
4730.52.....	I					
.....			4764.20			
4776.58.....	I					
4800.43.....	I					
4813.28*.....	3					
4819.57*.....	4					
4828.84*.....	6					
4837.97.....	I					
4842.35.....	I					
4883.51.....	I					
4907.50.....	I					
4921.86.....	I					
4943.16.....	I					
5041.17.....	6		5043	5045.5	5042.4	5042.715
5056.10.....	8		5057.3	5060.0	5057.1	5057.832
5092.00.....	I					
5101.42.....	0					
5113.70.....	I					
5182.13.....	I					

TABLE I—*Continued*

Wave-Length in Å. Units	Intensity	Rowland	Exner and Haschek	De Gramont	Lunt	Crookes
5185.64.....	I					
5193.21.....	I					
5196.62.....	I					
5202.85.....	2					
5219.05.....	I					
5240.63.....	O					
5295.66.....	O					
5417.36.....	I					
5438.58.....	I					
5456.61.....	I					
5469.18.....	I					
5472.90.....	I					
5494.82.....	O					
5576.23.....	O					
5589.18.....	O					
5593.82.....	O					
5632.72.....	O					
5639.13.....	I					
.....		5645.83				
5669.63.....	2	5665.78				
.....		5684.71				
5688.83.....	I	5690.65				
5694.68.....	O					
5701.26.....	I	5701.32				
5706.23.....	I	5708.62				
5716.08.....	I					
5739.20†.....	4					
.....		5772.36				
5785.45.....	O					
5800.25.....	I					
5806.30.....	I					
5845.06.....	I					
5867.33.....	2					
5914.7.....	I					
.....		5948.77		5948. P		
5957.80.....	2			5960.3	5960.3	5961.6
5979.20.....	2			5978.9	5981.3	5982.0
6329.71.....	I					
6339.39.....	2					
6347.01.....	6	6342.2	6347.1	6342.2	6346.9	6346.962
6363.10.....	I					
6371.09.....	4	6369.7	6371.4	6369.7	6372.2	6371.032
6662.3.....	I					
6671.2.....	I					

* Observed also by A. Fowler, "Silicon Lines in the Spectra of B-type Stars," Royal Astronomical Society, *Monthly Notices*, **76**, 196-197, 1916.

† Observed also by A. Fowler (*ibid.*).

a possible sixth. Several other frequency differences have been observed, but unless series can be found relating them, their significance may be questioned in many cases. For this reason they are omitted.

In conclusion it may be said that, so far as is known, the present work is the only extensive work on the spectrum of silicon which has been published in International units. The discovery of so large a

TABLE II
VACUUM-SPARK SPECTRUM OF SILICON
(A list of doubtful lines observed on one plate only)

Wave-Length in I.A. Units	Intensity	Wave-Length in I.A. Units	Intensity
2125.77.....	0	3420.32.....	0
2468.19.....	I	3423.66.....	0
2482.58.....	I	3430.51.....	0
2505.03.....	0	3499.61.....	I
2546.69.....	0	3651.66.....	2
2566.33.....	I	3661.97.....	0
2578.22.....	I	3670.49.....	I
2619.27.....	I	3681.38.....	I
2634.35.....	I	3779.47.....	I
2669.26.....	I	3837.65.....	I
2672.43.....	I	4141.04.....	0
2678.31.....	0	4304.15.....	0
2686.34.....	I	4321.81.....	0
2690.64.....	I	4324.40.....	0
2704.84.....	2	4598.21.....	0
2722.63.....	I	4599.62.....	0
2724.98.....	I	4624.91.....	0
2785.45.....	I	4627.35.....	0
2793.75.....	I	4657.20.....	0
2855.41.....	0	4659.17.....	0
2856.76.....	0	4900.48.....	0
2875.10.....	I	4949.72.....	0
2887.68.....	2	4958.19.....	0
2938.98.....	0	5105.98.....	0
2945.72.....	I	5108.94.....	0
2952.83.....	2	5206.66.....	0
2980.33.....	I	5392.75.....	0
2996.97.....	I	5448.46.....	0
3053.02.....	2	5451.91.....	0
3121.99.....	I	5466.70.....	0
3266.95.....	2	5540.16.....	0
3276.10.....	2	5622.36.....	0
3281.64.....	I	5796.71.....	0
3283.69.....	I	5813.50.....	0
3402.96.....	0	5827.16.....	0
3413.41.....	0	6079.23.....	0
3416.94.....	0	6099.73.....	0

number of new lines shows that for an element with which it is very difficult to get results when the usual light sources are used the vacuum-spark is a very powerful source.

